Milk Production of Holstein Heifers Fed Either Alfalfa or Corn Silage Diets at Two Rates of Daily Gain

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ABSTRACT

Seventy-five prepubertal heifers were fed diets based on either alfalfa silage or corn silage plus soybean meal for daily gains of either 725 or 950 g/d in a 2 × 2 factorial. Heifers were fed from 175 to 325 kg of body weight (BW). The alfalfa diet contained more digestible protein and less digestible energy than did the diet containing corn silage plus soybean meal. Actual gains were preexperimental BW gain, 633 g/d; lowest experimental BW gain, 785 g/d; highest experimental BW gain, 994 g/d; lowest postexperimental BW gain, 494 g/d; and highest postexperimental BW gain, 546 g/d. Compensatory postexperimental BW gains of heifers fed a common diet allowed the heifers to calve at 732 d of age. The postcalving BW was 508 kg, and precalving height at withers was 134 cm. A total mixed diet containing 17.1% CP and digestible energy at 3.12 Mcal/kg of dry matter was fed during lactation. Feed intake, milk and milk component production, and milk composition were not affected by either experimental diet or growth rate. As covariates, milk production was related to age at calving and was more strongly related to BW after calving, but no differences were observed among growth diets. Differences in protein and energy concentrations in experimental growth diets did not affect lactation performance. About 75% of total BW gains during the treatment period occurred before puberty, but rate of gain did not affect milk production. This lack of an effect of prepubertal growth rates on the milk production of primiparous heifers is consistent with six other similar studies that were conducted recently.
(**Key words**: heifer growth, growth diet, milk production, component production)

Abbreviation key: **ADG** = average daily gain.

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INTRODUCTION

Current recommendations are that Holstein heifers should calve at 24 mo and weigh from 550 to 625 kg prior to calving (7, 10). An average daily gain (**ADG**) of 767 g for 24 mo will add 560 kg to birth weights of 40 kg. An increase in the ADG of US Holstein heifers of 600 to 1200 g from 175 to 320 kg of BW decreased mammary parenchymal DNA and potential milk production (28). Subsequent production data (5, 12) have supported and strengthened the notion that ADG prior to conception can be optimized for milk production potential. Foldager and Sejrsen (4), Tucker (33), Johnsson (13), and Sejrsen (26) have reviewed aspects of this subject.

This study evaluated the milk production potential of US Holstein heifers from 175 to 325 kg of BW as affected by a planned ADG of either 725 or 950 g at two ratios of dietary protein to energy in the diets. The feeding and management practices during the growth of these heifers that were used for lactation are more completely described in the studies of Waldo et al. (37) and Capuco et al. (2), respectively, in which the components of the growth of heifers from 175 to 325 kg of BW and mammary growth and mammogenic hormones were described.

MATERIALS AND METHODS

Precalving Growth

Eleven time blocks of 4 heifers each were raised in 1984, and 10 time blocks of 4 heifers each were raised in 1985, to study milk production concurrently with four time blocks of 4 slaughtered heifers in each year (37). Heifers in these blocks of 4 were fed either alfalfa silage or a total mixed diet containing 78% (DM basis) corn silage plus 22% soybean meal (49% CP). The diets met NRC (20) requirements for Ca, P, and vitamins A and D. The diets were fed to produce either 725 or 950 g of ADG. Diets were identical for the 84 heifers monitored for milk production and for the 32 slaughtered heifers (2, 37). All heifers started the experimental diets at 175 kg of BW and continued on the experiment until they reached 325 kg of BW and had two or more estrous cycles based on plasma progesterone assays. All experimental heifers were housed in tie stalls in enclosed barns and fed once daily between 0900 and 1000 h. The two diets differed considerably in concentrations of digestible protein and energy and in the ratios of dietary protein to energy. The alfalfa silage diet contained 15.0% digestible protein and 3.16 Mcal of digestible energy/kg of DM or 47.5 g of digestible protein/Mcal of digestible energy. The diet containing corn silage plus soybean meal contained 11.1% digestible protein and 3.31 Mcal of digestible energy/kg of DM or 33.5 g of digestible protein/Mcal of digestible energy. Feed offered was adjusted weekly for DM changes and individual deviation from expected ADG. This experimental growth period and the diets used during this period were extensively described by Waldo et al. (37). During this period, all heifers were weighed and measured for height at withers weekly.

Growth after this experimental period until calving was observed under group management. During the observation period, diets that met the NRC (20) requirements for growth were fed. Breeding was started in time for expected calving at 24 mo of age. During this postexperimental period, all heifers were weighed and measured for height at withers monthly.

Cows Eliminated from the Study

Nine of the 84 original heifers were dropped from production analyses. One cow fed the alfalfa silage diet for a low ADG was killed by lightning in pasture before calving. Four cows fed the alfalfa silage diet for a high ADG were also eliminated from the study. One cow was found to have no functional reproductive tract. A second cow did not conceive after eight breedings. A third cow developed severe winged shoulders and was slaughtered after 68 DIM. A fourth cow was 196 DIM before being necropsied on August 12, 1987. The necropsy revealed bovine leukemia virus, joints infected with *Corynebacterium pyogenes*, glomerulonephritis, and enteritis, probably caused by *Campylobacter*. Three cows fed the diet containing corn silage and soybean meal for a low ADG were eliminated from the study. The cow that was expected to calve first in the experiment aborted. Two other cows had decubital ulcers, polyarthritis of joints, and decreased intake and milk production. One cow died at 58 DIM on July 20, 1987, and the other was slaughtered and necropsied after 84 DIM on July 31, 1987. One cow fed the diet containing corn silage and soybean meal for a high ADG was a difficult breeder, calved too late to be compared with other cows in lactation, and was dropped from the study. Another cow fed the alfalfa silage diet for a high ADG was included in the lactation summary at 231 DIM, but, subsequently, this cow died of bovine lymphosarcoma on May 11, 1987. Her production was consistent with the mean of the group at 231 DIM.

High temperatures from May through August 1987 produced considerable heat stress during this period of the lactation experiment. During summer, minimum and maximum temperatures were recorded in the open-sided barn that was used to house these cows, except for 4 d from May 1 through 4 and 5 d from August 19 through 23. These data were lost because of undetected recorder failures. High temperatures were equal to or greater than 30°C for 50 d and from 25 to 29°C for 41 d of the 114 d of records. Mean daily low and high temperatures were equal to or greater than 25°C for 49 d and from 20.5 to 24.5°C for 38 d. The mean high temperature for these 114 d was 28.1°C, and the mean of daily low and high temperatures was 23.3°C. These high temperatures likely contributed to the stress that precipitated the high incidence of sick cows during this period.

Daily DMI and milk production were recorded for 301 d and analyzed as 43-wk periods. The 75 cows analyzed included 12 cows with truncated lactations of less than 301 d. Three types of truncation were established prior to statistical analyses. These deletions were all terminal cow-weeks during which milk production was less than 10 kg/d or decreased more than 30% from the prior week or data were available for less than 7 d. Two cows fed the alfalfa silage diet for a low ADG had lactations lasting 280 and 287 d. Five cows fed the alfalfa silage diet for a high ADG had lactations of 231, 273, 287, 294, and 294 d. Five cows fed the diet containing corn silage plus soybean meal for a high ADG had lactations of 196, 252, 280, 287, and 287 d. No cows fed the diet containing corn silage plus soybean meal for a low ADG had lactations less than 301 d.

Lactation Diet

The ingredients of the lactation diet are presented in Table 1. The total mixed diet was fed for ad libitum intake once daily at 1400 h to cows in tie stalls in enclosed barns during winter. Daily individual total mixed diets and orts were weighed after calving for a total of 3173 cow-weeks during the milk production experiment. Weekly composite samples of the total mixed diet and orts were taken. Two changes were made to the total mixed diet. First, the alfalfa hay was ground in a hammer mill with a 2.54-cm screen and incorporated into the concentrate for 2118 cow-weeks; subsequently, the alfalfa hay was ground in a tub grinder (model 393; New Holland Co., New Holland, PA) with a 5.08-cm screen and was incorpo-

TABLE 1. Ingredients of total mixed diet fed during lactation.

Ingredient	
	(%)
Total mixed diet, DM basis	
Corn silage	35
Alfalfa hay	20
Concentrate	45
Concentrate, air-dry basis	
Corn	15
Barley	15
Soybean meal, 49% CP	13.254
$CaHPO_4$	1.00
Trace-mineralized salt with SE[1]	0.50
S, Elemental	0.09
MgO	0.04
Vitamin A premix[2]	0.044
Vitamin D premix[3]	0.016
Vitamin E premix[4]	0.048
ZnO[5]	0.00012

[1]Contains not >99.0 and not <94.0% NaCl, not <0.2% Mn, 0.1% Fe, 0.1% Mg, 0.05% Se, 0.025% Cu, 0.01% Co, 0.008% Zn, and 0.007% I.

[2]Contains 10,000,000 IU of vitamin A/kg.

[3]Contains 3,013,735 IU of vitamin D_3/kg.

[4]Contains 44,000 IU of vitamin E/kg.

[5]Started July 27, 1987 to supply 40 ppm of Zn in the total diet.

rated into the daily total mixed diet for 1055 cow-weeks beginning June 15, 1987. Second, no supplemental ZnO was added to the total mixed diet for 2500 cow-weeks; subsequently, supplemental Zn, as ZnO, was added for 673 cow-weeks beginning July 27, 1987. Both of these dietary changes were made in an attempt to minimize heat stress through nutritional management.

Some baled orchardgrass hay that was not analyzed was fed after calving to ease the transition of the cows to the total mixed diet. Occasionally, this orchardgrass hay was also fed later. After 2877 cow-weeks were completed, an outbreak of diarrhea occurred, and the orchardgrass hay was again used to help the heifers recover from decreases in DMI and milk production for the final 296 cow-weeks. Total use of orchardgrass hay DM represented 0.5% of the total DM offered.

Digestibility

Digestibility was measured at eight periods during the lactation period. In each period, 1 cow was assigned from each of the four experimental growth diets. Cows were adjusted to the collection stalls for 3 d before collection and sampling. During the next 7 d, DMI plus total collection of feces, urine, and milk were measured. Samples of the total mixed diet, orts for individual cows, and proportional samples of the total mixed diet, orts, feces, urine, and milk were taken and stored frozen until analyzed.

Lactation Measurements

Cows were milked twice daily, and daily milk weights were recorded. Samples were taken weekly from consecutive a.m. and p.m. milkings for analyses of fat, protein, lactose, and TS. Weekly BW were also recorded during lactation.

Chemical Analyses

A total of 120 weekly composite samples for the assay of DM were dried to a constant weight in a 100°C forced-air oven. Simultaneously, weekly samples of total mixed diet were stored frozen until primary grinding for analyses using a vertical cutter mixer (model VCM-40; The Hobart Manufacturing Co., Troy, OH). Except when the sample represented the week of a digestion trial, the weekly sample was combined with a second weekly sample during this primary grinding. A secondary grinding was performed in the laboratory using an impact grinder (model 3600 Plus; Vita-Mix Corp., Cleveland, OH). Dry ice was used to reduce particle size for duplicate chemical analyses in the wet state. Samples for analyses were not weighed until the dry ice was completely converted to CO_2. The NDF, nonsequential ADF, acid detergent lignin, and CP that is insoluble in hot water were determined by the methods of Goering and Van Soest (6), and CP that is insoluble in ruminal fluid after autoclaving was determined by the method of Waldo and Goering (36). Total N was determined by macro-Kjeldahl (1) modified to use boric acid in distillation, ash was determined at 600°C for 16 h, and gross energy was determined by adiabatic calorimeter using a polyethylene bag of known energy content as a primer. The two consecutive milk samples taken weekly were analyzed (Environmental Systems Services, College Park, MD) individually for fat, protein, lactose, and TS by infrared analysis (1). Proportional milk samples collected during the digestion trials were analyzed for total N by macro-Kjeldahl (1).

Statistical Analyses

The means and standard errors for composition and digestibility of the lactation diet were computed using PROC MEANS of SAS (25). Data on the growth of cows used in the lactation trial and that of slaughtered heifers were analyzed as individual degree of freedom contrasts of 1) alfalfa silage diet versus diet containing corn silage and soybean meal, 2) low versus high ADG, 3) the interaction of diet and ADG, and 4) residual, which was used as the error based on Steel and Torrie (30). Milk production data were analyzed using these same contrasts. The PROC GLM of SAS (25) was used for these analyses.

RESULTS

Identical growth parameters are presented in Table 2 for the 32 slaughtered heifers and in the first three sections in Table 3 for the 75 heifers that were used later in lactation. The only growth data published in the study of Waldo et al. (37) were those for daily gain during the experimental growth period. Data on the slaughtered heifers are presented first to compare similarities and differences in growth between the two groups.

Growth Before Slaughter

The physical growth of the 32 heifers that were slaughtered (37) is described in Table 2 as 1) age and BW at the end of the preexperimental period and ADG during this period; 2) age, BW, and height at withers at puberty; and 3) age and BW at the end of the experimental feeding period and ADG during this period. The calculation of preexperimental ADG assumed a BW of 40 kg at birth. Preexperimental BW was greater ($P < 0.01$) for heifers fed for a high ADG than for those fed for a low ADG (181 vs. 178 kg). Age at puberty was greater ($P < 0.05$) for heifers fed the alfalfa silage diet than for those fed the diet containing corn silage plus soybean meal (348 vs. 323 d), and an interaction ($P < 0.05$) occurred because heifers fed the alfalfa silage diet for a high ADG were younger than those fed the alfalfa silage diet for a low ADG, but heifers fed the diet containing corn silage plus soybean meal for a high ADG were older than those fed the diet containing corn silage plus soybean meal for a low ADG. The BW at puberty for heifers fed the diet containing corn silage and soybean meal was 50 kg greater ($P < 0.01$) for heifers fed for a high ADG than for heifers fed for a low ADG, but BW at puberty for heifers fed the alfalfa silage diet at both ADG were identical. Height at withers at puberty demonstrated an interaction ($P < 0.05$) between diet and ADG because the change from a low ADG to a high ADG within the alfalfa silage diet was –1 cm

TABLE 2. Growth of slaughtered heifers.

	Alfalfa silage diet[1]		Corn silage diet					
	Low ADG[2]	High ADG	Low ADG	High ADG	SE	Diet	ADG	Interaction
Heifers, no.	8	8	8	8	. . .	. . .	. . .	. . .
Preexperimental period								
Age, d	227	236	229	229	5.6	NS[3]	NS	NS
BW, kg	178	181	179	181	0.9	NS	**	NS
Gain, g/d	611	603	606	616	17.7	NS	NS	NS
Puberty								
Age, d	360	336	311	335	10.3	*	NS	*
BW, kg	272	272	244	294	8.7	NS	**	**
Height at withers, cm	119	118	115	121	1.4	NS	†	*
Experimental period								
Age, d	432	397	420	382	7.0	†	***	NS
BW, kg	335	338	329	333	3.1	NS	NS	NS
Gain, g/d	766	974	792	1004	22.5	NS	***	NS

[1]Alfalfa silage diet contained 15.0% digestible protein and 3.16 Mcal of digestible energy/kg of DM or 47.5 g of digestible protein/Mcal of digestible energy. The corn silage diet was supplemented with soybean meal and contained 11.1% digestible protein and 3.31 Mcal of digestible energy/kg of DM or 33.5 g of digestible protein/Mcal of digestible energy.

[2]Average daily gain. Low ADG = 725 g/d; high ADG = 950 g/d.

[3]$P > 0.10$.

†$P < 0.10$.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

and within the diet containing corn silage and soybean meal was 6 cm. During the experimental growth period, the ADG was an imposed treatment that caused an older age ($P < 0.001$) at completion for heifers fed for a low ADG than those fed for a high ADG (426 vs. 389 d). The final age was greater ($P < 0.10$) for heifers fed the alfalfa silage diet than for those fed the diet containing corn silage plus soybean meal (414 vs. 401 d).

Growth Before Lactation

Growth parameters of the 75 heifers prior to parturition are described in Table 3. Data are comparable with those presented in Table 2 with additional data for age, precalving height at withers, postcalving BW, and ADG from the end of the experimental period to calving. No preexperimental differences ($P < 0.10$) were observed in age, BW, or prior ADG for these 75 heifers that were randomly assigned to the four experimental growth diets. Age at puberty was greater ($P < 0.05$) for heifers fed for a low ADG than for heifers fed for a high ADG (352 vs. 333 d). Experimentally imposed ADG was greater ($P < 0.001$) for heifers fed for a high ADG than for heifers fed for a low ADG, which caused an older ($P < 0.001$) age at the end of the experimental growth period for heifers fed for a low ADG than for heifers fed for a high ADG (418 vs. 383 d). The mean BW for the first 3 d after calving indicated an interaction ($P < 0.05$) of diet and ADG. Heifers experimentally fed the alfalfa silage diet for a low ADG and those fed the diet containing corn silage plus soybean meal for a high ADG had greater BW than did the other two groups of heifers. The ADG after the experimental growth period was greater ($P < 0.05$) for heifers fed for a low ADG than for those fed for a high ADG (546 vs. 494 g), and an interaction ($P < 0.05$) occurred because the difference between ADG for heifers fed the alfalfa silage diet was greater than the difference between ADG for heifers fed the diet containing corn silage plus soybean meal (95 vs. 10 g). The final height at withers

TABLE 3. Growth of heifers used in milk production comparison.

	Alfalfa silage diet[1]		Corn silage diet					
	Low ADG[2]	High ADG	Low ADG	High ADG	SE[3]	Diet	ADG	Interaction
Cows, no.	20	17	18	20	...	...	...	...
Preexperimental period								
Age, d	223	231	226	218	5.9	NS[4]	NS	NS
BW, kg	180	179	181	180	1.0	NS	NS	NS
Gain, g/d	635	609	635	648	18.1	NS	NS	NS
Puberty								
Age, d	352	346	353	320	9.1	NS	*	NS
BW, kg	275	289	277	284	8.0	NS	NS	NS
Height at withers, cm	119	118	120	120	1.0	NS	NS	NS
Experimental period								
Age, d	412	388	424	379	7.5	NS	***	NS
BW, kg	329	334	334	339	4.0	NS	NS	NS
Gain, g/d	793	992	776	997	20.4	NS	***	NS
Postexperimental period								
Age, d	750	722	738	719	16.5	NS	NS	NS
BW,[5] kg	523	493	496	514	11.1	NS	NS	*
Gain, g/d	573	478	519	509	21.3	NS	*	*
Height at withers, cm	134	133	134	136	1.0	†	NS	†

[1]Alfalfa silage diet contained 15.0% digestible protein and 3.16 Mcal of digestible energy/kg of DM or 47.5 g of digestible protein/Mcal of digestible energy. The corn silage diet was supplemented with soybean meal and contained 11.1% digestible protein and 3.31 Mcal of digestible energy/kg of DM or 33.5 g of digestible protein/Mcal of digestible energy.

[2]Average daily gain. Low ADG = 725 g/d; high ADG = 950 g/d.

[3]Appropriate for n = 17.

[4]$P > 0.10$.

[5]After calving.

†$P < 0.10$.

*$P < 0.05$.

***$P < 0.001$.

TABLE 4. Composition of total mixed diet fed during lactation.

Component	Concentration	
Samples, no.	66	
	$\overline{X}$	SE
DM,[1] % (as fed)	55.4	0.29
OM, % of DM	94.0	0.05
NDF, % of DM	32.1	0.36
ADF, % of DM	18.3	0.21
ADL,[2] % of DM	2.84	0.04
CP, % of DM	17.1	0.09
H_2O-CP,[2] % of DM	11.1	0.12
AR-CP,[2] % of DM	12.2	0.21
Energy, Mcal/kg of DM	4.46	0.005

[1]For DM, n = 116.

[2]ADL = Acid detergent lignin, H_2O-CP = CP that is insoluble in hot water, and AR-CP = CP that is insoluble in rumen fluid after autoclaving.

prior to calving was greater ($P < 0.10$) for heifers fed the diet containing corn silage plus soybean meal than for heifers fed the alfalfa silage diet (135 vs. 133 cm), and an interaction ($P < 0.10$) occurred because heifers fed the alfalfa silage diet at a low ADG were 1 cm taller than those fed the alfalfa silage diet at a high ADG, but those fed the diet containing corn silage plus soybean meal at a low ADG were 2 cm shorter than heifers fed the diet containing corn silage plus soybean meal at a high ADG. This group of 75 heifers used in the lactation trial had a greater ADG ($P < 0.10$) prior to the experimental period than did the 32 heifers that were slaughtered (633 vs. 608 g). This difference was the only difference between the groups.

Lactation Diet Composition

The DM of the total mixed diet fed over a period of 120 wk during lactation was 55.4% (Table 4). The DMI, CP concentration, and ADG concentration met or slightly exceeded NRC (20) requirements for maintenance, ADG, and milk production.

TABLE 5. Digestibility and N balance of total mixed diet fed during lactation.

Component	Digestibility	
Trials, no.	32	
	$\overline{X}$	SE
DM, %	67.8	0.37
OM, %	67.8	0.37
Energy, %	69.2	0.44
NDF, %	49.5	1.24
ADF, %	43.1	0.99
ADL,[1] %	3.0	3.47
CP, %	67.9	0.59
N Balance, g/d	7.0	4.66

[1]Acid detergent lignin.

Lactation Diet Digestibility

The mean DMI during digestion trials (Table 5) was 16.6 versus 17.5 kg/d during the lactation trial. Milk production was 22.1 versus 22.8 kg/d, respectively. The digestible energy concentration was 3.12 Mcal/kg of DM, which met the NRC (20) requirements for maintenance, ADG, and milk production. Mean N consumption was 452 g/d; 32.1% was excreted in feces, 40.3% was excreted in urine, 26.0% was secreted in milk, and 1.5% or 7 g/d was retained.

BW, Feed Intake, and Milk Production

The experimental growth diets yielded no differences ($P < 0.10$) in mean BW, total DMI, DMI as a percentage of BW or daily digestible energy intake during lactation (Table 6). Similarly, the experimental growth diets yielded no differences in milk or 4% FCM production, daily component production, or component percentage. Milk production was not related to age at puberty (used as a covariate), was related ($P < 0.05$) to age at calving (used as a covariate), and was related ($P < 0.01$) to BW after calving (used as a covariate). The most significant covariate, BW after calving, did not yield any significant differences in milk production among growth treatment means.

The adequacy of DMI is particularly surprising after the measurement of 619 cow-weeks during the heat stress of the summer of 1987 and the measurement of 296 cow-weeks after a severe incidence of diarrhea.

DISCUSSION

Tucker (33) described mammary growth in four physiological stages. The two stages that occur prior to first parturition are 1) between birth and conception and 2) between conception and first parturition. Earlier work of Sinha and Tucker (29) described a stage of allometric mammary growth during which mammary DNA, as a measure of cell number, increased at 3.5 times BW. For the Holstein heifers in that study, this period of allometric growth occurred between 3 and 9 mo of age or between 92 and 229 kg of BW. Puberty occurred at a mean age of 7.4 mo or at an interpolated BW of 195 kg. This rapid allometric growth extended beyond puberty and through the first few estrous cycles.

Because puberty occurred at such a young age or at such a low BW in the study of Sinha and Tucker (29) relative to our study (342 d and 281 kg) and others (31), it seems reasonable to calculate from their data that the age at puberty of 7.4 mo was 73% through this 3- to 9-mo phase of rapid allometric mammary growth and a BW of 195 kg at puberty was 75% through this 92- to 229-kg phase of rapid allometric mammary growth. If we assume that the experimental growth of the heifers in our study prior to puberty represented rapid allometric mammary growth, then we might assume that rapid growth continued to 399 d of age for heifers fed for a low ADG and continued to 373 d of age for heifers fed for a high ADG; these ages are 19 and 10 d, respectively, prior to the end of the experimental growth period (Table 3). Similarly, if we assume that the experimental growth of heifers in our study prior to BW at puberty represented rapid allometric mammary growth, then we might assume that rapid growth continued to a BW of 308 kg for heifers fed for a low ADG and continued to 323 kg of BW for heifers fed for a high ADG; these BW are 23 and 13 kg, respectively, prior to the end of the experimental growth period (Table 3). These calculations suggest that our experimental period of growth might have extended very little beyond the period of rapid allometric mammary growth.

If effects of nutrition are observed, mammary growth and ultimate milk production are inversely related to growth rates from birth to conception. The best support for this inverse relationship between growth rate prior to conception and milk production has been Danish experiments that generally use either identical twins or paternal halfsibs and large numbers of cattle. Red Danish cattle produced maximum milk when they had an ADG of 600 g from 150 to 300 kg of BW (3). Similarly, Red Danish or Black and White Danish cows had nearly maximum milk production when they were fed for an ADG of 600 g from 100 to 300 kg of BW (5). Danish Jersey cows had maximum milk production when they were fed for an ADG of 421 g from 46 to 200 kg of BW (12). Another study of 62% large Danish breeds and 38% small Jersey cows had maximum milk production when they were fed for an ADG of 517 g (11), which is consistent with the expected calculation (421 ×

TABLE 6. Body weight, feed intake, milk and milk component production, and milk composition.[1]

	Alfalfa silage diet[2]		Corn silage diet		
	Low ADG[3]	High ADG	Low ADG	High ADG	SE[4]
Cows, no.	20	17	18	20	. . .
BW, kg	535	520	521	531	10.6
DMI					
kg/d	17.5	17.2	18.0	17.4	0.45
% of BW	3.29	3.32	3.45	3.30	0.081
Digestible energy, Mcal/d	54.4	53.3	55.7	54.0	1.38
Milk, kg/d	22.8	21.6	24.0	22.9	0.95
FCM, kg/d	20.7	19.8	21.7	20.9	0.80
Fat					
g/d	772	742	810	781	32.0
%	3.46	3.50	3.45	3.49	0.107
Protein					
g/d	758	731	797	768	28.8
%	3.35	3.44	3.37	3.40	0.047
Lactose					
g/d	1157	1108	1227	1166	49.7
%	5.05	5.12	5.11	5.08	0.038
TS					
g/d	2847	2732	3002	2875	110
%	12.56	12.76	12.62	12.67	0.140

[1]$P > 0.10$; no significant differences occurred.

[2]Alfalfa silage diet contained 15.0% digestible protein and 3.16 Mcal of digestible energy/kg of DM or 47.5 g of digestible protein/Mcal of digestible energy. The corn silage diet was supplemented with soybean meal and contained 11.1% digestible protein and 3.31 Mcal of digestible energy/kg of DM or 33.5 g of digestible protein/Mcal of digestible energy.

[3]Average daily gain. Low ADG = 725 g/d; high ADG = 950 g/d.

[4]Appropriate for n = 17.

0.38 + 600 × 0.62 = 532 g). All of these Danish experiments found that higher ADG prior to conception reduced potential milk production.

An example of excessive ADG during early growth on subsequent milk production occurred in US Holstein calves nursed on the milk of their dams for ad libitum intake, similar to the manner in which beef calves are nursed on their dams (22, 23). Nine of these Holstein heifers gained 950 g/d for the 7 to 8 mo of nursing, calved at 21.4 mo of age for their first lactation, and produced only 74% as much milk during the first 6 mo of lactation as contemporary Holstein heifers raised as dairy replacements that calved at 24.6 mo of age. Regressions of production on BW and age at calving were not significant; therefore, most of the effect must have been caused by rapid ADG. Milk production of British Friesians (18) was decreased in all lactations by rapid growth management, and additional decreases in the first two lactations were caused from early breeding.

Beef cows with a high BW at weaning, presumably, have low milk production and give birth to calves that have low BW at weaning when weaning occurs at about 7 mo. Hereford cows sorted into high, medium, and low groups based on their BW at weaning gave birth to calves with low, intermediate, and high BW at weaning, respectively (19). Johnsson and Morant (14) found that the mean BW of calves at weaning decreased 5 kg for every 10 kg of increase in the BW at weaning of their dams. Johnsson and Obst (15) found that the lower BW at weaning for calves from the group of cows fed for high gain initially and subsequently fed for medium gain were compensated by higher fertility and lower mortality. Such an inversion of BW at weaning is established in the 7- to 8-mo period of nursing. If growth rate is regulated prior to conception, milk production is inversely related to ADG.

Conversely, if effects of nutrition are observed from conception to parturition, greater ADG without excessive fattening is directly related to increased milk production. British Friesians fed at 840 g of ADG from 12 mo of age to 1 mo before calving produced more milk than five groups of heifers fed at lower ADG for the same age period (17). An ADG of 970 g from 8 to 14 mo of age was less detrimental to the subsequent milk production of Herefords than was an ADG of 910 g from 2 to 8 mo of age (15). If effects of gain are observed from conception to parturition, ADG without excessive fattening is directly related to milk production.

Compensatory ADG occurred after the experimental period in our study so that BW after calving was not affected by either experimental ADG or diet. Differences in experimental ADG prior to conception should have been inversely related to milk production, but differences after conception should have been directly related to milk production. These cows calved at 732 d with a BW of 508 kg after calving and a final height at withers prior to calving of 134 cm. The final height at withers before first parturition and BW after parturition were very similar to other data on Holsteins at first parturition (8, 31) and approached a precalving BW of 616 kg at 24 mo as observed in survey data of Holsteins (10), if we assume a mean calving BW loss of 65 kg (32).

The diet containing corn silage plus soybean meal with 3.31 Mcal of digestible energy/kg of DM produced less gut fill and more empty BW gain than did the alfalfa silage diet with 3.16 Mcal of digestible energy/kg of DM. Our diets contained 11.1 and 15.0% digestible protein or 33.5 and 47.5 g of digestible protein/Mcal of digestible energy, respectively. The alfalfa silage diet had more protein per unit of energy than did the diet containing corn silage and soybean meal. Both protein concentrations were adequate for protein deposition expected relative to observed energy deposition in the growth of the slaughtered heifers in our study (37). Dietary energy concentrations of 0.73 or 0.90 Scandinavian feed units/kg of DM fed to produce a similar ADG did not affect milk production (27).

Our prepubertal ADG, which ranged from 776 to 997 g from BW of 180 to 330 kg, did not cause differences ($P < 0.10$) in milk production or milk composition. Peri et al. (21) fed heifers from 6 to 10 mo of age for an ADG of 0.625, 0.768, and 1.100 kg and from 10 to 12 mo of age for an ADG of 1.162, 0.707, and 0.797 kg and observed milk production during 250 d of lactation at 7056, 6070, and 5975 kg, respectively. Milk production for the latter two groups was similar but lower than that for the first group. Similar prepubertal ADG from 715 to 950 g from weaning to a BW of 320 kg did not produce significant differences in milk production (34, 35). Radcliff et al. (24) fed Holstein heifers from 126 kg to a BW at slaughter of 336 to 411 kg for an ADG of either 0.8 or 1.2 kg without affecting milk production potential. An ADG from 661 to 903 g from 6 to 16 mo of age yielded a positive linear effect ($P < 0.10$) on milk production (32) rather than an expected inverse linear effect. Hoffman et al. (9) did not observe an expected positive postpubertal effect on milk production when the ADG was set from 763 to 969 g from 10 mo of age to parturition. Lacasse et al. (16) used an ADG from 0.71 to 0.86 kg from 1 yr of age to 3 mo of gestation followed by an ADG from 0.66 to 0.96 kg from 3 mo of gestation to 14 d before calving without yielding a significant difference in milk production.

One must question whether Holsteins in North America do not have a larger mature BW and a greater milk production potential than do the larger Danish breeds, which consistently have maximum milk production when fed for an ADG of 600 g from 100 to 300 kg of BW, much as the smaller Danish Jersey cows have maximum milk production when fed for an ADG of 421 g from 46 to 200 kg of BW. Holsteins in the US may possibly grow at an ADG of 800 g from 150 kg to 350 kg of BW without a reduction in potential milk production.

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